

**METHOD AND APPARATUS FOR REDUCING PRINTING
ARTIFACTS OF STITCHED IMAGES**

FIELD OF THE INVENTION

The present invention is in the field of exposure systems. More particularly, the present invention provides a method and apparatus for combining ("stitching") more than one image segment to produce a larger image without creating a visible seam or other artifacts at the interface between the multiple image segments.

BACKGROUND OF THE INVENTION

Raster output scanning is commonly used in a number of applications, including flatbed scanning recorders, capstan imagesetters and platesetters and even some external or internal drum systems. In a typical flat field imaging application, a photosensitive material, for example, is moved at constant speed by a capstan roller or other linear conveyor means, fed from continuous rolls or precut cassettes of stacked material to present the material to a stationary optical system for scanning. Alternatively, stationary photo-sensitive material may be imaged by translating the optical system. The scan optic in the flat field imaging context typically consists of a resonating or rotating single facet mirror, or an assembly of two or more mirrors, or a glass prism consisting of one or two reflecting surfaces. It is also common to have a rotating polygon or hologon having multiple reflective or refractive facets symmetric to a central rotating axis.

Within the flat field applications, a rotating polygon scan optic has greater potential for speed and efficiency compared to the use of the resonating scanner or single facet rotary scanner. The polygon scan optic is presently preferred because for each

rotation thereof, a polygon scan optic having "n" number of facets produces "n" number of scan lines, whereas for the single facet rotary scan optic or resonating scanner, each revolution of the scan optic produces only one scan line. Thus, to obtain a high resolution image on a given imaging surface in as short an amount of time as possible, it is desirable to maximize the scan rate of the scan optic.

However, in flatbed raster recording systems, such as computer-to-plate systems, technical and cost hindrances limit the practical length of the scan line. This generally limits the page width of these systems to a range of about 6 to about 24 inches.

In an attempt to overcome this page width limitation, efforts have been made, with limited success, to combine the partial scan lines produced by more than one imaging source, or produced by one source at different times, into a single, composite image. For example, it is common to write two or more adjacent pages and mechanically stitch them together. However, it is difficult to precisely butt two printed pages together. As a result, the seams between the partial scan lines produced by each imaging source can be highly visible in the composite image.

Additional artifacts produced by cross-scan errors, pixel size variations, exposure variations and other factors, may also be introduced, further diminishing the quality of the composite image. An undesirable source of error in optical scanning systems results from in-scan error. In-scan error specifically refers to errors in the placement of scan lines in a direction parallel to the lines themselves. Sources of in-scan errors may include variations in the rotational speed of the polygon mirror, pixel timing, clock jitter and mechanical errors such as bearing noise and facet rotational error.

5 Past attempts to join multiple image segments together have been largely unsuccessful at eliminating a visible seam where the image segments have been joined or have involved complex processing. The present invention incorporates many unique features which eliminate these and other problems associated with the use of multiple image segments to create a single larger image.

10 In summary, the prior art has yet to disclose or teach singularly, or in any combination, and there continues to be a significant need for, a method and apparatus for combining ("stitching") multiple image segments to form a larger composite image without a visible seam where the image segments have been
15 joined.

SUMMARY OF THE INVENTION

20 The present invention provides various methods and apparatus for eliminating artifacts in an image formed using more than one image segment. For example, the present invention provides a unique stitching method for eliminating visible seams in the image by creating a first buffer region in a first image segment in which the intensity of the pixels in the first buffer region is attenuated, a buffer region in a second image segment in which
25 the intensity of the pixels in the second buffer region is attenuated, and then overlapping the buffer regions of the two image segments. The present invention provides for the buffer region to be defined as an area of an image comprising a number of pixels from one image segment and a number of pixels from an adjacent image segment. The present invention further provides
30 in a particular preferred embodiment that the intensity of the pixels in the buffer region of each image segment may be attenuated by the use of a device to modulate the intensity of the scanning beam or beams.

BRIEF DESCRIPTION OF THE DRAWINGS

5 The features of the present invention will be best understood from a detailed description of the invention and a preferred embodiment thereof selected for the purposes of illustration and shown in the accompanying drawings in which:

10 FIG. 1 shows a schematic diagram of two image segments and an exemplary buffer zone on each image segment according to one exemplary embodiment of the present invention.

FIG. 2 shows a schematic diagram of intensity versus position for two image segments with buffer zones according to one exemplary embodiment of the present invention.

15 FIG. 3 shows a block diagram general flowchart of one exemplary embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

20 In a typical flatbed laser raster output scanner, an image is generated by "painting" a two dimensional raster image. One dimension is generated by scanning the laser beam or beams in the "fast scan" (horizontal) direction while the other dimension is generated by more slowly transporting the object or recording medium in a direction orthogonal to the fast scan (vertical or "slow scan"). The source of the printed data is typically
25 generated from a database that is usually arranged in a rectilinear bitmap to be compatible with the raster scanned cathode-ray tube display and usually consists of digital data in binary form, either text or halftone images. In other words, the intensity of any one pixel may only be one of two levels of gray.
30 However, in some cases, data for the raster image may be multi-level data. The exposed object is typically a photosensitive surface such as a printing plate, a xerographic drum, silver-halide film, or other photosensitive coated substrate. Although the present invention is described in the context of an exemplary
35 embodiment, laser raster scanning, the invention would be useful

in any system where a pattern of information is being transferred to a sensitive medium. Thus, in the context of the present invention, "printed" or "printing" should be understood as encompassing any method of exposing, scanning, or recording a pattern of information on a sensitive medium.

The image width is limited by the width capability of the fast scan device. To generate an image wider than that produced by the fast scan device, it is common to first expose the photosensitive media surface with an image segment whose size is selected to be equal to or less than the maximum scan width of the fast scan device. Then, either the photosensitive media or the scanning device itself is indexed to the next adjacent recordable area on the photosensitive media. The raster output scanner then prints another image segment, thereby creating a composite image larger than the first image.

For example, to create an exposed printing plate that is X inches wide and Y inches long with a flatbed laser raster output scanner that is X/2 inches wide, one approach is to first expose an X/2 by Y inch segment by raster scanning in the X (fast scan) direction with a scan of X/2 width while translating the plate underneath the operating raster output scanner in the Y (slow scan) direction a distance Y. Next, the slow scan stage is moved to its starting position while the raster output scanner, or the platen holding the printing plate, is indexed by a distance X/2 to the remaining unexposed segment, and the exposure process is repeated. The result is two adjacent butted image segments where the composite image is X inches wide by Y inches long.

Unfortunately, due to mechanical inaccuracies of the scanning system, it is difficult to seamlessly butt the image segments together and the result is often a visible seam artifact that is usually objectionable to the observer. For example, if the slow scan stage that transports the photosensitive plate is not aligned to the fast scan translation, then the butt joints

where the image segments are seamed together may be either overlapped or underlapped, creating dark or light areas readily apparent to the casual observer. A typical gap or overlap is usually a fraction of a pixel in width, but can exceed one pixel in systems with poor mechanical tolerances. A gap or overlap of only a fraction of a pixel, even with the smallest pixel sizes, may be sufficient to create a visible artifact in an image. A characteristic size of a pixel may range from a few micrometers to several tens of micrometers.

The present invention in one exemplary embodiment compensates for a seam gap or overlap by digitally filtering the border pixels, in real-time or just prior to exposure, overlapping the adjacent image segments by the spatial width of the digital filter, and printing a hybrid binary/gray scale image to achieve a less objectionable seam. The digital filter is usually effective in one dimension along the fast scan direction, but a two-dimensional filter, i.e. in both the fast scan and slow scan directions, can also be employed.

In order to seamlessly stitch image segments together the following procedure is generally applied. Prior to exposing a first image segment A, the width of image segment A is increased within the digital database by adding a small number of pixels from a second image segment B, adjacent to image segment A. This addition of pixels to image segment A creates a new image segment A'. It should be noted that although the images in the exemplary embodiment of Figure 1 are the same size and rectangular in shape for ease of explanation, the images may be of different heights and/or widths and do not have to be rectangular in shape, but rather can be of any regular or irregular shape. As shown in Figure 1, the number of pixels added from the adjacent image segment can be defined by the value K. When image segment A' is printed, most of the pixels of image A' will be scanned unmodified. However, a number of pixels before the border of

image segment A', in a region called the buffer region, are scanned with attenuated intensity levels.

5 First, a buffer region must be defined. The buffer region is normally a rectangular area along the edge of the vertical (slow scan) axis of the image segment to be printed. Although a rectangular area is used for ease of explanation, the buffer region may be of any shape along the vertical axis as is desired
10 to correspond to the border with the adjacent image segment or image segments to be combined, such as sinusoid, slanted, or even irregular, such as to follow the contour of an object shown in an image. As shown in Figure 1, the buffer region comprises K pixels from image segment B and K pixels from image segment A for
15 a total width of 2K. A buffer region of an equal number of pixels on both image segments was also chosen for ease of explanation. However, it is not necessary for the same number of pixels to be used from both image segments.

The practical width of the buffer region is limited by the
20 width of the scan lens being used or by the integrator being used. A scan lens may limit the width of the buffer region because creating a scan line wider than the scan lens width is not physically possible. An integrator may limit the width of the buffer region based on its word length. An 8-bit integrator,
25 for example, would limit the buffer region to 256 pixels because it can only hold data for 256 pixels at a time. A practical range of widths for the buffer region is presently thought to be between about 8 to about 32 pixels wide although narrower or wider buffers may still function properly. If the buffer region
30 is too wide, too much of the image may be attenuated and the quality of the image may be reduced. If the buffer region is too narrow, too few pixels may be attenuated and a visible seam may still appear.

As image segment A' is printed, a pixel counter **10** keeps
35 track of how many pixels have been exposed. A pixel may be

defined as the smallest logical unit on the raster scale of visual information that can be used to build an image. Pixels
 5 for the purposes of the exemplary embodiment are about 20 to about 25 microns in size, but, depending upon the exposure application, can vary from a fraction of a micron to tens of microns. The pixel counter is initialized to zero at the beginning of each scan. When the pixel counter reaches the first
 10 border of the buffer region, set at a predetermined pixel value, attenuation of image segment A' in its buffer region is triggered.

As shown in Figure 3, upon input from a start-stop switch
 12 at a certain pixel value, an initial value 14 and a ramp rate
 15 16 are assigned to an integrator 18. The ramp rate is the rate at which the recording beam intensity will be varied across the buffer region and it is measured in percentage of modulation per in-scan pixel. For example, if the recording beam intensity was to be varied over a buffer region of 32 pixels, the ramp rate is
 20 100%/32. The integrator then calculates an intensity value by integrating the positive or negative ramp rate across the buffer region. The slope of the ramp may be dictated by the width of the buffer region. The intensity value may also be a constant or derived from a look-up table. Non-linear effects may be
 25 achieved by adding additional integrators or other non-linear Digital Signal Processing (DSP) type devices. These may consist of delay lines, look-up tables, code generators or other similar devices. Additionally, this technique is not limited to binary data, but can be extended to multi-level data since the essential
 30 requirement is to multiply the data value by an attenuation value. A typical integrator used in this invention is an 8-bit integrator which would allow a buffer region of up to 256 pixels.

Normally, a printing plate is exposed with binary, two-level pixels. However, in the buffer region, the printed pixels in one
 35 exemplary embodiment of the present invention must possess a gray

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scale attribute. In other words, their intensities in such an embodiment must be one of more than two levels of gray. The
5 requisite number of gray levels is heuristically determined. Too few levels of gray and the seam filter may be less effective. Too many levels of gray makes the system very complex. The gray scale modulation is typically achieved by amplitude modulation of the recording beam, either externally or internally.

10 In order to achieve the necessary recording power onto common photosensitive surfaces, often high power lasers or other types of high optical intensity exposure sources are used. In an exemplary embodiment of the present invention, a laser 20 which emits a frequency or frequencies matching the photosensitivity of the printing plates can be used. Since the
15 intensity of some lasers cannot be modified internally, the lasers are typically run in a continuous wave (CW) mode or a quasi-continuous mode and a separate laser beam intensity modulation system is used.

20 Any electro-optical modulator will achieve a similar effect as the AOM. U.S. Pat. No. 4,746,942 and U.S. Pat. No. 4,316,196, which provide examples of electro-optic modulators, are hereby incorporated by reference herein.

Also, other means that could be used to generate the
25 required gray levels might include pulse width modulation (PWM) or interference modulation.

Commonly used in laser beam intensity modulation systems are devices called acousto-optic modulators (AOMs). AOMs are beam diffracting devices, which, in an inactivated state, transmit the
30 beam directly through the crystal substrate, referred to as the zero-order beam or light, and when activated by a radio-frequency source, diffract the beam at a known angle, referred to as the first-order beam or light.

In most image recorders using AOMs in the laser beam
35 intensity modulation system, the first-order light from the AOM

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is used to expose the photosensitive media. In other words, when a given region of the photosensitive media is exposed, the AOM is activated to allow the laser beam to pass through an optical path that leads to the photosensitive media. In an inactivated state, the zero-order light passing through the AOM does not reach the photosensitive media, being dumped outside the optical path.

10 The use of the first-order light to expose the photosensitive medium works well as a strategy for meeting the exposure requirements of common digital media. The first-order beam provides a very high dynamic range between the light levels of the first-order beam and that relatively insignificant scattering that is transmitted along the optical path when the AOM is inactivated. As a result, there is little clouding of the medium due to incidental exposure of those areas of the photosensitive medium that are intended to not be exposed based upon the image.

20 Once the intensity value has been computed by the integrator, the intensity value and pixel data **28** from the material to be digitally exposed are entered into a multiplier **22** which converts the data from digital to analog by using a Digital-to-Analog Converter (DAC). DACs are integrated circuits which utilize various techniques to receive a digital data element and produce a corresponding analog voltage.

30 The DAC outputs an intensity value (a voltage) which drives an AOM **24**. A laser beam is directed through the AOM and the AOM controls the intensity of the outgoing laser beam. The AOM and its associated electronic input amplifier are designed to accept any DAC intensity value between and including 0 and 1 volt. At 0 volts, the AOM diffracts substantially 0% of the laser beam and at 1 volt, the AOM diffracts substantially 100% of the laser beam. At any value between 0 and 1 volt, the AOM diffracts a percentage of the laser beam based on the following formula: the

intensity out is equal to the intensity in multiplied by the sine squared of the voltage ($I_{out} = I_{in} \sin^2 V$). The voltage into the AOM causes an ultrasonic wave to pass through an optically transparent material which causes periodic variations of the refraction index and diffracts light according to the formula above. An example of an acceptable transparent material for the AOM is crystalline quartz. However, any suitable substitute material possessing acceptable acousto-optic properties will suffice for this purpose.

Any electro-optical modulator will achieve a similar effect as the AOM. U.S. Pat. No. 4,746,942 and U.S. Pat. No. 4,316,196 which are examples of electro-optic modulators are hereby incorporated by reference herein. Also, other means that could be used to generate the required gray levels might include pulse width modulation (PWM) or interference modulation.

A pulse width modulated output signal from a PWM circuit, typically utilizing a central processor (CPU), comprises a train of pulses at a fixed frequency and having widths proportional to values of data samples. Thus, the PWM output signal may be considered as composed of a baseband signal and a carrier frequency. In order to filter out the carrier frequency from the baseband signal as in a digital to analog application, a low-pass filter is typically connected at the output of the PWM circuit. U.S. Pat. No. 5,255,351, which is incorporated by reference herein, describes a pulse-width modulation device for controlling shapes of dots printed out by a printer by regulating shapes of pulses of PWM signals, which respectively represent gray levels of pixels of an input image.

The presently preferred method of laser intensity modulation in this invention is amplitude modulation (AM) through the use of an Acousto-Optic Modulator. However, laser intensity modulation may be accomplished in a number of other ways, including frequency modulation (FM), phase modulation (PM), or

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code domain modulation (CDM) techniques. As opposed to amplitude modulation, which directly modifies the intensity of any one pixel, all of these techniques (FM, PM, CDM) modify the average intensity of a set of pixels by means of adjusting when they are turned on. Thus, these methods may be used with binary pixels and there is not a need for pixels possessing a gray scale attribute. When an observer views a printed page from a normal distance, FM, PM, or CDM techniques achieve a blending effect similar to the amplitude modulation process.

FM uses pixel duration timing hardware to change the time of exposure of the pixel within the buffer region. A fast subpixel clock is required, typically 4 to 16 times faster than the main pixel clock. If the pixel is turned on full intensity for X number of pixels, then completely off for X number of pixels, the average intensity would be 0.5. A ramp can be created by varying the On/Off time of the binary subpixels for each pixel in the buffer zone. The effect is very similar to the AM technique, except that in AM, the intensity into the AOM is constant for one pixel and its value can be analog (gray scale), whereas an FM modulated pixel retains a binary amplitude value. An FM ramp function is created by gradually incrementing or decrementing the subpixel time setting versus pixel position.

PM makes use of pixel placement timing hardware to actually vary the pixel position of the last pixel, or last group of pixels, in either a set pattern or a deterministic, quasi-random manner. In PM, the last K pixels on the first line of the first image are essentially being stretched (or shrunk) while the first K pixels of the first line of the second image are being shrunk (or stretched) by making the pixel timing positions slightly closer together. The stretching can be by a fraction of a pixel or by whole pixels. On the second line this could be repeated or reversed (shrinking the pixels on the first image while stretching them on the second). As the scan proceeds down

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the seam, the end of the left line and the beginning of the right
line vary in a deterministic, quasi-random manner. The pattern
5 of shrinking and stretching can be established by a line counter
that drives a pattern generator (implemented as a lookup table).

Once the digital data is diffracted by the AOM, the
diffracted data travels to a polygon motor **26** where it is sent
through a scan lens. The present invention uses non-telecentric
10 scanning although a telecentric scan lens would result in even
better artifact reduction. Telecentric scan lenses arc lasers
in such a way that the cone of light converging toward focus at
a spot in the focal plane is substantially perpendicular to the
focal plane for all scan angles. These scan lenses allow the beam
15 to scan normal to the surface of the photosensitive material,
rather than at an angle. Scanning at an angle normal to the
surface may allow mechanical tolerances of the flatbed and its
positioning system to be relaxed. However, for best results, the
material should be held as flat as possible. This may be
20 achieved, among other ways, by using a vacuum to hold the
material flat against a surface. Image segment A' is printed by
the imaging system.

The process articulated above may now be repeated with image
segment B'. As shown in Figure 1, image segment B' comprises the
25 same K pixels from the edge of image segment A as were included
in image segment A' and all of image segment B. One change in
the process from image segment A' to image segment B' may be that
in the buffer region of image segment B', the intensity levels
are attenuated in an opposite manner to those in the buffer
region of image segment A'. As shown in Figure 2, the intensity
30 levels in the buffer region of image segment A' may ramp from 1
(full-scale) to 0. On the other hand, the intensity levels in the
buffer region of image segment B' may ramp from 0 to 1 (full-
scale). Image segment B' now may be printed onto a
35 photosensitive material and the buffer region of B' will in the

exemplary embodiment be printed over the buffer region of A'.
When the buffer regions are overlapped, the intensity in the
5 exemplary embodiment shown will always substantially be equal to
1 (full-scale). Deviation from full intensity will only occur to
the extent the images do not overlap exactly, but any deviation
will only occur at a fraction of full intensity. Thus, as shown
in this embodiment, the visible seam between the two images will
10 be significantly reduced. The cumulative exposure on the plate
is the same as if the pages had been exposed to one wide scan
line. The net effect is a higher quality image without a
noticeable and objectionable butting artifact.

Although limited embodiments of a stitching method and
15 apparatus have been described and illustrated herein, many
modifications and variations will be apparent to those skilled
in the art. For example, the intensity of a laser beam is
modified in this exemplary embodiment by the amplitude modulation
of an Acousto-Optic Modulator. However, the same effect may be
20 reached by modifying the intensity of a set of pixels by
frequency modulation, phase modulation, or code domain
modulation. In another exemplary embodiment, the buffer region
is described as rectangular and comprises an equal number of
pixels in both images. However, the buffer region may be of any
25 shape along the vertical axis (e.g. sinusoid, concave, or even
follow the outline of an object in an image) and it does not need
to comprise an equal number of pixels in each image. Also in an
exemplary embodiment, a gas laser is used to scan the material.
However, any light or radiation source matched to the
30 photosensitive media and capable of being directed to transfer
a pattern of information can be used to achieve the same purpose.
Also, rather than a flying spot laser raster scanner, it is
possible to expose the same pattern with fixed pattern, multi-
element light sources where the intensity of individual emitting
35 elements can be independently modulated, especially in the buffer

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region, to achieve a reduced butting artifact. The multi-element light source can be an array of laser diodes or light emitting devices, or an array of individually addressed light valves or micro-mirrors illuminated by a light source such as an incandescent light bulb or an arc lamp.

From the foregoing description, it is apparent that many variations and modifications of the above described structures and procedures may be practiced without meaningfully departing from the scope of the invention. Accordingly, the foregoing description should not be read as pertaining only to the precise structures and procedures described, but rather should be read consistent with and as support for the following claims for the fullest and fairest scope.